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PRECIPITATION IN THE GREAT PLAINS

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[Weather Bureau, Washington, D. C., January 1938.]

The revision of the general table of the Weather Bureau Climatological Data according to sections rather than on a State-wide basis, effective January 1, 1936, presented an excellent opportunity to reexamine precipitation data for the Great Plains section.

It was possible to extend the data to a uniform 50-year period from 1887 to 1936, in those cases where the original data did not cover the above period. Extrapolation of data was performed cautiously and extensions were made with care, but it must be realized that data for some early periods are based on fewer stations than in later years. It is believed, however, that the data are homogeneous as near as it is practicable to make them and comparisons drawn therefrom may be accepted as accurate to a close approximation.

Precipitation data have been computed for long-time trends for individual stations in the Great Plains region and several trend studies have been made on a State-wide basis. The subdivision of the six major States of the area, from North Dakota southward, gave an opportunity to study the climatic aspect of various sections separately.

An interesting feature of the study is the inadvertent checking of the uniformity of the subdivisions from a climatological viewpoint. It is well known that the natural vegetation and soils of the Great Plains do not conform to the arbitrary divisions of the States. A casual comparison of the natural vegetation map with the soil type map (1) indicates a close relationship between them. What could be more natural than to assume a causal relationship with the climate? Thornthwaite (2) develops this more fully and an examination of his maps of climatic years indicates a close relationship.

The actual eastern boundary of the Great Plains has been variously described and is uncertain. Numerous investigators place it at varying intervals from the eastern limit of the dark-brown soils, the extent of the short grass, or the average position of the 20-inch annual rainfall isohyetal. In a report to the President, the Great Plains committee (3) includes practically all of North and South Dakota and Nebraska, roughly two-thirds of Kansas, one-half of Oklahoma, and the northwestern third of Texas. With these variously suggested boundaries, it is very difficult to adjust climatic boundaries to conform as closely as practicable to logical limits.

It is also difficult to secure the exact climatic characteristics that should be used in differentiating regions. Equal annual rainfall has been considered as typifying certain regions, while Thornthwaite (*loc. cit.*) has developed rainfall indices based on rainfall-evaporation resultants. The latter is undoubtedly more significant than any single climatic factor, but there are certain phases of the problem, as brought out by him and other authors, that should be considered. For example, it is noted by Kincer (4) that in considerable areas from 55 to more than 65 percent of the warm season precipitation

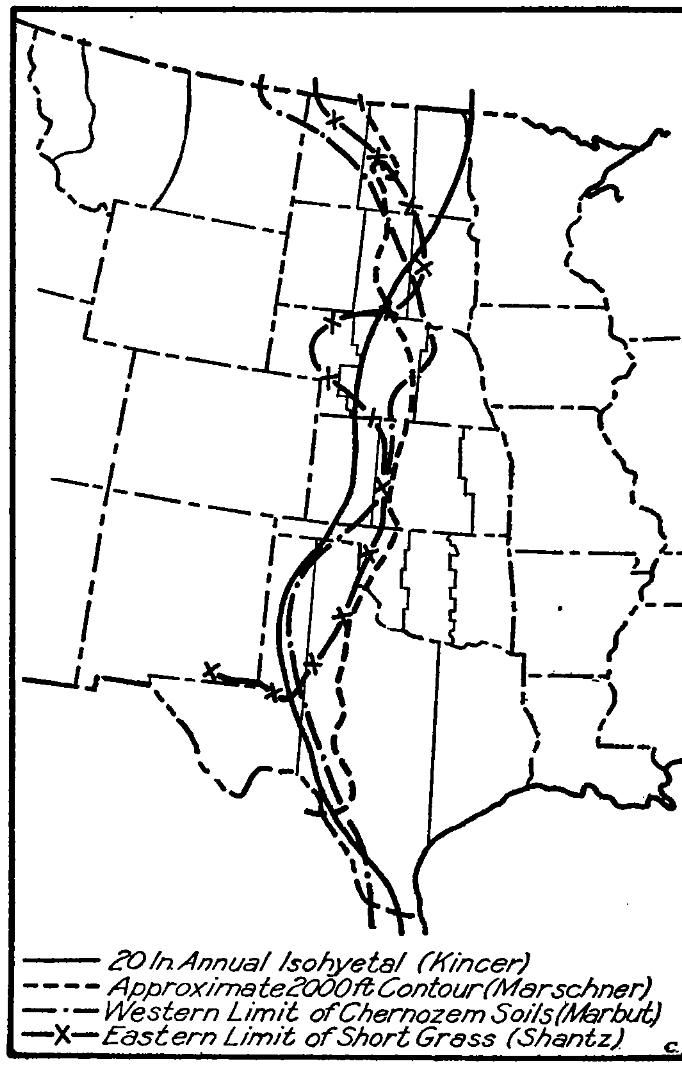

FIGURE 1.—Subdivisions of States in the Great Plains region and various natural boundaries.

falls at night. While this may not be significant from the viewpoint of total accumulations, the occurrence at a time of minimum evaporation is highly significant from the standpoint of effective precipitation.

Kincer shows also (5) that less than 10 percent of the annual precipitation in the Great Plains occurs during the winter months (December–February), and that from 40 to over 50 percent occurs during the summer months (June–August). Included in the same study are a number of charts illustrating the average number of days with precipitation in varying amounts from 0.01 inch to over 2.00 inches. It is noteworthy that in the Plains area the number of days with precipitation from 0.01 to 0.25 inch vary from 40 to 80 days and mostly less than 1 with precipitation over 2.00 inches. And on still another page is a chart showing the percentage of years with 30 consecutive days or more without 0.25 inch of rainfall in 24 hours from March to September, inclusive. This is probably one of the most significant of the various charts as regards the Great Plains. The chart indicates that practically all of the Plains has such a dry period 70 percent of the time, or 7 years in 10, on the average, while the western boundary usually has such a dry period 90 to 100 percent of the years.

These significant features all combine to justify the inclusion by Jefferson (6) of this region in the semi-arid zone. Ward (7), however, includes much of the Great Plains area in the "Eastern" type, including in his classification most of the Great Plains area from eastern North Dakota southward roughly to central Texas. This division is more or less arbitrarily made on the 20-inch mean annual isohyetal and the 2,000-foot contour line. Thornthwaite (*loc. cit.*) also includes roughly the same area as Jefferson in the semi-arid zone.

All these climatic subdivisions, however, only agree approximately with the natural vegetation and soil province distribution. If we are to accept the theory that natural vegetation and soil are a result of long-time climate, or rather an accumulation of weather, it is quite possible that certain phases have not been included in the climatic studies. It may well be that some weather elements, such as distribution and intensity of rainfall, should be considered. Thornthwaite (8) has already shown in Oklahoma that certain patterns of intensities do occur and that the erosion of soils may be directly related to different intensities of rainfall.

The frequency of certain amounts of precipitation has always had a bearing on its effectiveness. It is axiomatic that a large number of slow, relatively gentle rains are more favorable for agriculture than a single heavy downpour. It is also well known that precipitation, in general, represents what is known as a skewed distribution when long-time averages of amounts are considered. The median of an array of precipitation data is ordinarily found to be somewhat less than the arithmetic mean. Also, the mode, or most frequent amount, is generally somewhat less than the mean.

Ordinarily, for well-distributed rainfall, such as in the eastern United States, a quite even distribution of the data is found, with the median only slightly below the mean and the mode slightly below the median. This frequency distribution might well be termed a "normal" distribution. In regions such as the Great Plains, however, the greater frequency of dry years or seasons distorts the curve considerably, with the median appearing an appreciable distance below the mean and the mode quite a ways below the median. This study of precipitation in the Great Plains has verified these characteristic distributions in most instances. Occasionally the distribution was found to be very much distorted by a bimodal phase, particularly noticeable in the fall months in western sections.

For the purposes of this study, the States were used exactly as subdivided in the table mentioned at the beginning of the article—Figure 1 shows the subdivisions. The States of Colorado, New Mexico, Minnesota, Iowa, Missouri, Arkansas, and Louisiana were not divided, and those from North Dakota southward to Texas were considered as the Great Plains proper, although the eastern portions of the tier to the westward should properly be considered.

As indicated before, the subdivisions were also considered in their relation to a logical division of the Plains. It becomes readily apparent from the map that the divisions have no direct relation to either vegetative, climatic, or soils classification. This also becomes evident in considering the data obtained from the study.

As an aid in handling the data, all rainfall data were reduced to percentages of the 50-year averages. These percentage figures were then arrayed in frequency distributions as follows: Under 50 percent; 50 percent to 69 percent; 70 percent to 89 percent; 90 percent to 109 percent; 110 percent to 129 percent; 130 percent to 149 percent; and 150 percent and over. Under this array, the midpoints of the groups fall in the following manner: 40 percent, 60 percent, 80 percent, 100 percent, 120 percent, 140 percent, and 160 percent, assuming, of course, that the midpoints of the end groups fall as specified. This is, of course, an erroneous assumption, but for the purpose of discussion they may be used as indicated. Also, no attempt has been made to verify the assumption of the midpoints of the groups falling as indicated.

Furthermore, it is realized that the use of frequency distributions for as few data as 50 is liable to errors of greater or less magnitude. However, the indicated frequencies are based on a larger period of record than has heretofore been available. The percentages determined from these distributions should not vary materially for some time to come, as a 50-year record is usually considered fairly satisfactory for climatological purposes.

Figure 2 shows the average spring, summer, autumn, and March–August precipitation for the 50-year period 1887–1936. The regular decrease in amount from east to west is indicated clearly, also the marked lack of spring precipitation in western Texas and New Mexico.

Table I shows the percent of the years with frequencies of seasonal precipitation as indicated. One of the most striking features of this table is the lack of unusually low percentages in the summer in western Texas. The frequencies in this group are also low in the eastern States of the area. It is natural that the percentages for the longer periods should be closer to the normal, hence the reductions in number of extreme percentages in the March-August data. The percentages are low in both extremes in this group, but are significant in eastern Montana and some western portions of the central group of States. An unusual feature of the fall tabulation is the high percentage of the extremely low precipitation in western Montana.

Figure 3 shows the rainfall variability as measured by the percentage of years with precipitation more than 30 percent greater or less than normal. It is believed to be a valuable indicator of the frequency of extremes of rainfall, including as it does those falls of greater than 130 percent and less than 70 percent. Within these figures, of course, considerable variation in crop conditions may occur, depending on other weather items than precipitation, but if the major portions of precipitation of an area occur within these limits it may be safely concluded that precipitation is quite stable for agriculture.

The variability of spring precipitation (March–May), is based on a 50 year record. It varies widely in more than one-third of the years in most of the region and nearly half the years in central North Dakota. Western Texas shows conspicuously as an area of wide precipitation fluctuations in this season of the year, with the percentage 54, or well over half the years.

Similar conditions are shown for the summer months (June–August). During this season precipitation becomes more stable in many sections, markedly so in western Texas, New Mexico, and Colorado. A similar percentage decline is noted in Nebraska, but marked increases appear in central and western Montana and in Oklahoma.

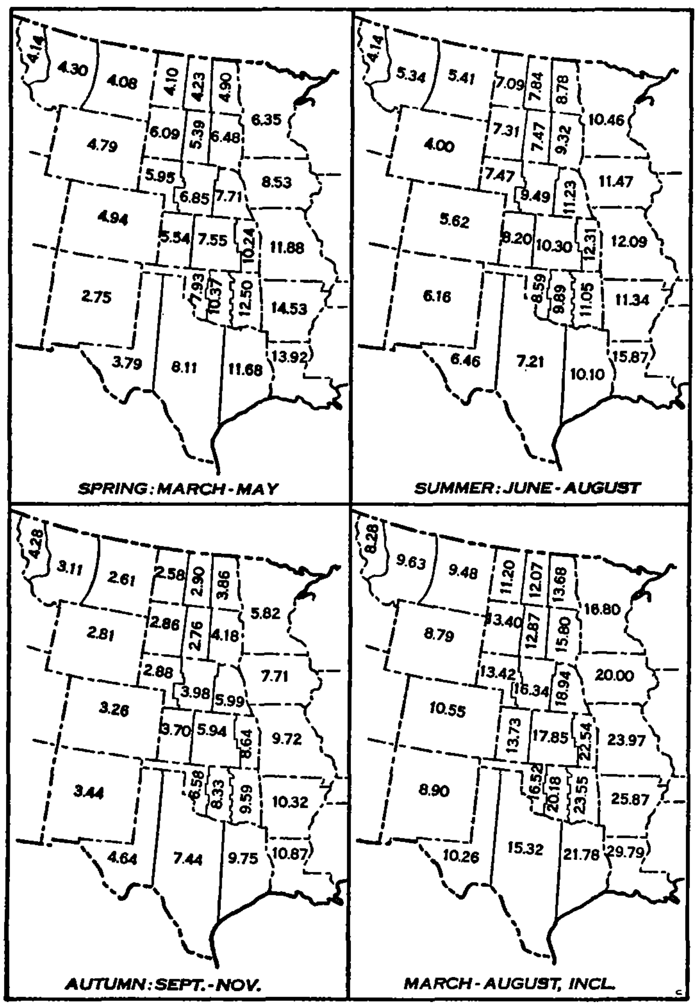

FIGURE 2.—Average precipitation.

For the autumn season (September-November), variations become unusually marked during this season, rising remarkably in practically all sections. The fluctuations become particularly noteworthy in western Oklahoma, and from western Kansas northward through Nebraska and the central Dakotas. There is a slight tendency to more stable precipitation in central Montana and Missouri.

The period March-August, inclusive, covers the season of growth for most crops. It is natural for smaller percentages to be recorded, as previously noted, but significant values are shown in several districts. Variations are marked in central Montana, western South Dakota, western Nebraska, and central and western Texas. An unusual feature of this chart is the abnormally large percentage shown in eastern Oklahoma. Quite stable precipitation is indicated for Colorado, probably due to the inclusion of data from all stations in the State average.

Figure 4 is a companion to figure 3, showing rainfall variability under droughty conditions. It indicates the percent of the years with precipitation less than 70 percent of normal, and is based on the assumption that such moisture conditions may be considered as approaching the minimum necessary for plant growth, particularly in western portions of the Plains where the rainfall is normally light.

Large drought percentage frequencies are shown in the western Dakotas, western Kansas and Oklahoma, and western Texas and New Mexico. Rather stable precipitation is indicated in Arkansas, Colorado, Wyoming, western Montana, and central and eastern Texas. The figures for the first three States above may be due, again, to use of State averages rather than by sections.

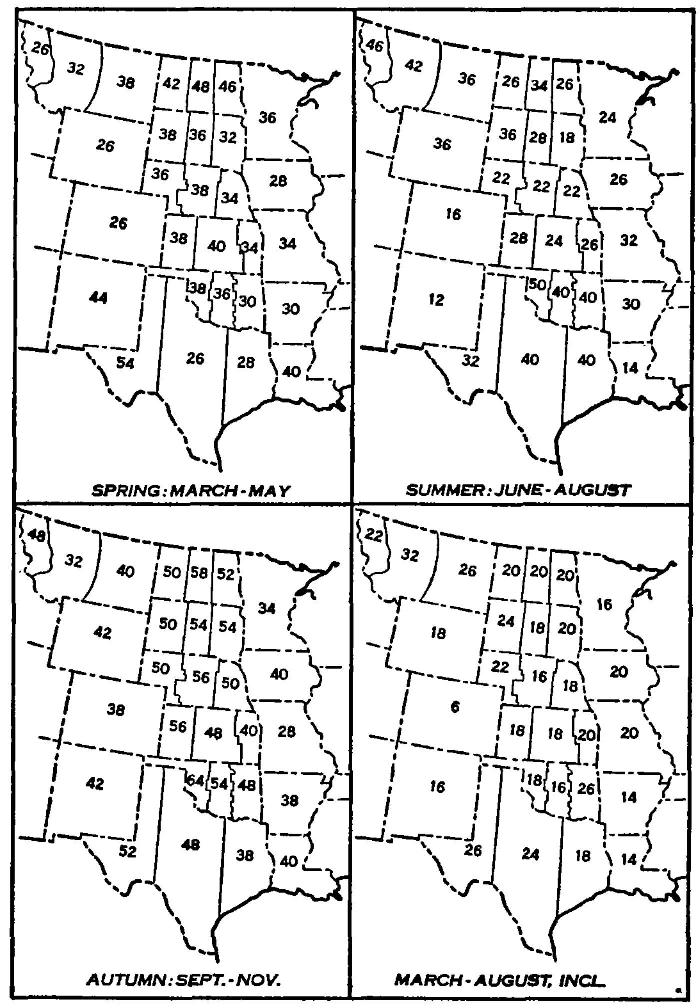

FIGURE 3.—Rainfall variability, percent of time precipitation varied 30 percent, or more, from normal.

The dry year variability for the summer is evident. Again, marked variation is indicated in Oklahoma, particularly the western portion, while quite marked deviations are noted in Texas and Montana. Rather remarkable stability is indicated in Colorado and New Mexico, and as this cannot be due entirely to State averages, it indicates a more dependable moisture condition for summer crops than in some sections farther east.

There is shown a marked increase in frequency of dry years in the autumn; this is particularly marked in western

Texas, New Mexico, and in Kansas and Nebraska. Approximately 3 years out of 10 are dry in the fall in most of the central Plains area; and in some sections, notably western Oklahoma, the count rises to nearly 4 years out of 10.

The warm season (March to August) shows the same general decline in values as the previous one for the same period. Percentages are less, compared with individual seasons, but significant tendencies to dry seasons appear in western Kansas and Nebraska, as well as in central and western Texas. Central and western Montana also show relatively large percentages, but marked stability is again shown in Colorado and Louisiana. The latter State usually has adequate precipitation for any needs.

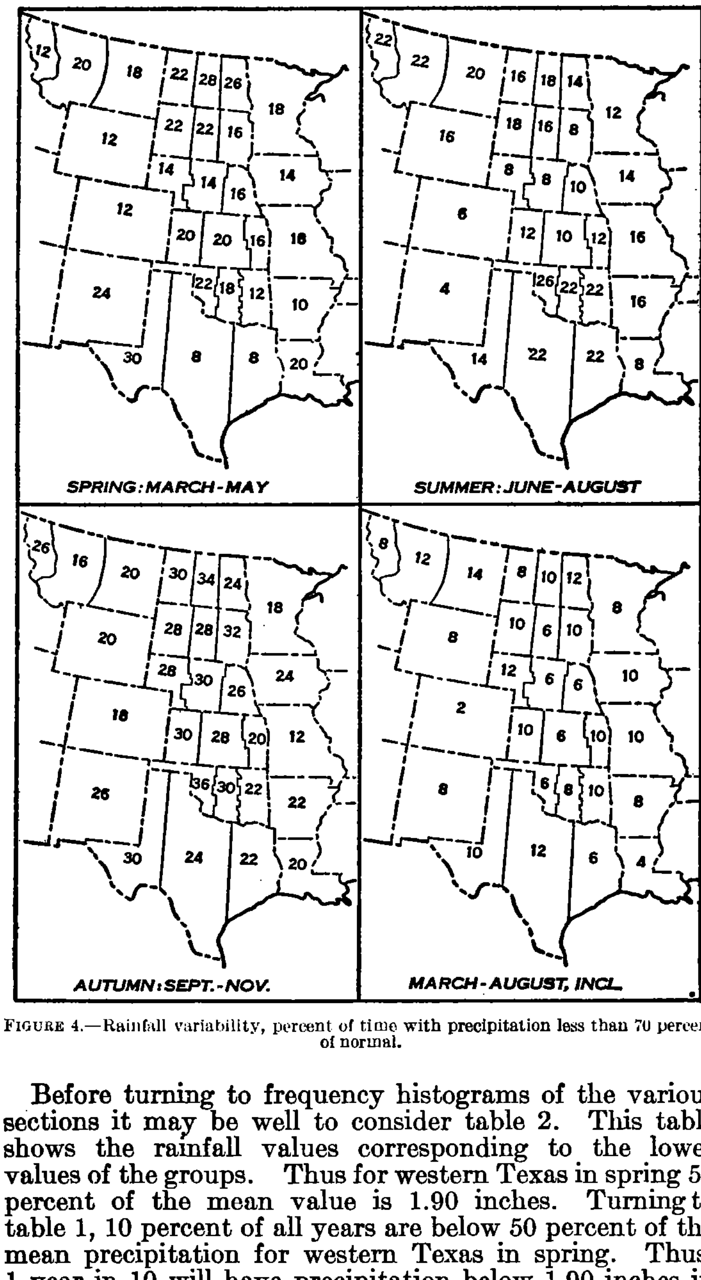

FIGURE 4.—Rainfall variability, percent of time with precipitation less than 70 percent of normal.

Before turning to frequency histograms of the various sections it may be well to consider table 2. This table shows the rainfall values corresponding to the lower values of the groups. Thus for western Texas in spring 50 percent of the mean value is 1.90 inches. Turning to table 1, 10 percent of all years are below 50 percent of the mean precipitation for western Texas in spring. Thus, 1 year in 10 will have precipitation below 1.90 inches in spring. This reduces to approximately 0.63 inch of precipitation a month. As the average number of days with 0.01 inch or more in western Texas ranges from 3 to 7, with an average of 5, it will be readily seen that average individual rains under the above conditions do not ordinarily exceed 0.13 inch. Under normal conditions in this region, with relatively warm days and high evaporation, such rains are scarcely sufficient to support vegetation, unless it be a highly drought-resistant type. Assuming for example, an average rainfall of 0.25 inch on 5 days a month, or monthly totals of 1.25 inches, the spring precipitation would then be 3.75 inches. For agricultural purposes this amount would leave little to spare yet it will be seen from tables 1 and 2 that 74 percent of the years in western Texas have less than 3.75 inches in spring.

The situation is somewhat better in summer as the average rainfall in this region is then 6.46 inches, or 2.15 per month—roughly, 0.43 inch per day. Half of this amount reduces to 0.22 inch per day. However, considering the increased evaportion resulting from the higher temperatures, the moisture situation appears precarious for plant growth. The record shows that summer rainfall in western Texas during the 50 years under consideration has been greater than the 50 percent minimum.

The autumn season represents the greatest precipitation hazard. The frequency of years below 70 percent becomes abnormally large during this season and the corresponding values of rainfall range generally below 1.75 inches in the western group of States, except western Montana. In the central Plains States, particularly the central and western portions, the fall precipitation, for the years with less than 50 percent of normal, ranges below 2 inches, and mostly under 3 inches for all years below 70 percent of normal, except in southern districts. This again indicates a daily minimum level of around 0.10 to 0.20 inch of precipitation, based on an average of 5 days with rain each month.

Tables 1 and 2 have been concerned primarily with individual States or sections of States. Histograms were constructed from averages of different sections of the Great Plains. For this phase the area was divided as follows: Western Section: Montana, Wyoming, Colorado, and New Mexico; Central Section: North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, and Texas; Eastern Section: Minnesota, Iowa, Missouri, Arkansas, and Louisiana.

In the following discussions of the histograms, the use of the term "mode" is in accordance with the approximate mode used by Mills (**11**). The formula used by him is as follows: Mo=Mean−3(mean−Md). While this is not an exact value, the relatively few data scarcely require a more elaborate computation.

The spring precipitation histogram (figure 5) for the western Great Plains illustrates the general tendency to slightly skewed distribution of precipitation previously mentioned, with the approximate mode 93 percent. The central Great Plains histogram presents a markedly skewed diagram, with the general tendency leaning heavily toward the lower percentages. In this diagram the mode is 89 percent, or well toward the lower part of the diagram. The great frequency of lesser amounts is marked in the central Great Plains, where much of the spring precipitation falls in less than normal amounts. The eastern sections revert back to a modified skewness, with the mode 94 percent.

Summer precipitation histograms for the Great Plains represent nearly a normal frequency distribution, with the modes for the western and central diagrams falling only 2 or 3 percent below the mean. Also for the eastern sections the mean, median, and mode practically coincide, representing as nearly a symmetrical frequency distribution as could be expected to obtain in unrelated data.

TABLE 1.—*Percent of years with precipitation in frequencies shown*

	Spring							Summer							Fall							March–August, inclusive						
	Under 50 percent	50–69 percent	70–89 percent	90–109 percent	110–129 percent	130–149 percent	150 percent and over	Under 50 percent	50–69 percent	70–89 percent	90–109 percent	110–129 percent	130–149 percent	150 percent and over	Under 50 percent	50–69 percent	70–89 percent	90–109 percent	110–129 percent	130–149 percent	150 percent and over	Under 50 percent	50–69 percent	70–89 percent	90–109 percent	110–129 percent	130–149 percent	150 percent and over
Montana:																												
Eastern	10	8	28	18	16	8	12	2	18	16	24	24	12	4	10	10	16	28	16	14	6	4	10	14	40	20	12	0
Central	4	16	14	28	26	6	6	10	12	18	24	16	10	10	8	8	26	20	22	4	12	2	10	26	30	12	20	0
Western	0	12	22	34	18	12	2	6	16	18	28	8	12	12	18	8	14	20	18	12	10	0	8	34	22	22	10	4
Wyoming	2	10	28	20	26	14	0	4	12	24	20	20	16	4	6	14	26	18	14	12	10	0	8	22	40	20	10	0
Colorado	0	12	30	24	20	10	4	2	4	30	32	22	4	6	2	16	20	30	12	12	8	0	2	26	46	22	4	0
New Mexico	16	8	22	24	10	6	14	2	2	26	38	24	6	2	10	16	12	22	24	6	10	0	8	26	34	24	2	6
North Dakota:																												
Eastern	6	20	12	22	20	14	6	6	8	16	30	28	8	4	6	18	18	20	10	22	6	2	10	14	36	30	8	0
Central	12	16	12	20	20	10	10	4	14	12	38	16	12	4	10	24	12	14	16	14	10	2	8	20	34	26	10	0
Western	8	14	24	24	10	8	12	8	8	12	36	26	4	6	14	16	12	16	22	8	12	4	4	30	24	26	12	0
South Dakota:																												
Eastern	6	10	26	16	26	8	8	2	6	26	30	26	6	4	10	22	14	16	16	12	10	0	10	22	32	26	10	0
Central	6	16	16	18	30	6	8	2	14	20	28	24	4	8	16	12	18	14	14	10	16	4	2	26	36	20	10	2
Western	8	14	18	14	30	8	8	2	16	24	26	14	10	8	8	20	10	24	20	12	6	2	8	26	30	20	10	4
Nebraska:																												
Eastern	2	14	30	16	20	10	8	2	8	28	30	20	4	8	8	18	16	20	14	14	10	4	2	24	42	16	6	6
Central	8	6	34	22	6	14	10	2	6	26	42	10	8	6	10	20	20	8	16	14	12	2	4	30	34	20	6	4
Western	4	10	34	24	6	16	6	0	8	28	34	16	8	6	10	18	16	18	16	6	16	0	12	22	36	20	6	4
Kansas:																												
Eastern	0	16	24	28	14	12	6	6	6	28	26	20	4	10	8	12	22	20	18	12	8	2	8	18	38	24	4	6
Central	6	14	18	28	14	10	10	4	6	36	20	20	2	12	8	20	12	14	26	12	8	4	2	28	34	20	10	2
Western	4	16	18	22	22	10	8	2	10	26	28	18	12	4	8	22	20	16	8	12	14	2	8	22	34	26	6	2
Oklahoma:																												
Eastern	2	10	30	22	18	12	6	10	12	16	24	20	6	12	8	14	24	18	10	12	14	2	8	30	28	16	12	4
Central	4	14	24	28	12	6	12	4	18	22	20	18	6	12	12	18	10	26	10	12	12	2	6	24	36	24	4	4
Western	6	16	22	18	22	8	8	6	20	18	20	12	12	12	16	20	8	8	20	16	12	0	6	30	26	26	10	2
Texas:																												
Eastern	2	6	34	32	6	12	8	6	16	16	22	22	8	10	6	16	20	26	16	6	10	0	6	34	30	18	8	4
Central	2	6	40	22	12	8	10	2	20	16	26	18	10	8	6	18	20	22	10	12	12	0	12	26	30	20	8	4
Western	10	20	24	16	6	6	18	0	14	26	22	20	12	6	8	22	8	26	14	8	14	0	10	32	22	20	12	4
Minnesota	2	16	22	32	10	8	10	2	10	20	28	28	12	0	4	14	12	38	16	10	6	0	8	20	42	22	8	0
Iowa	4	10	22	28	22	8	6	2	12	22	34	18	10	2	2	22	12	26	22	8	8	0	10	20	38	22	8	2
Missouri	0	18	18	30	18	10	6	2	14	16	38	14	12	4	6	6	28	22	22	10	6	2	8	22	34	24	8	2
Arkansas	2	8	32	24	14	18	2	2	14	20	30	20	8	6	4	18	16	28	18	8	8	0	8	22	36	28	4	2
Louisiana	2	18	20	26	14	12	8	2	6	20	40	26	6	0	8	12	28	20	12	6	14	0	4	34	28	24	10	0

Notes at end of table.

TABLE 2.—*Normal precipitation (in 100-percent column), together with precipitation values corresponding to lower group limits of table 1*

	Spring							Summer							Fall							March–August, inclusive						
	50 percent	70 percent	90 percent	100 percent	110 percent	130 percent	150 percent	50 percent	70 percent	90 percent	100 percent	110 percent	130 percent	150 percent	50 percent	70 percent	90 percent	100 percent	110 percent	130 percent	150 percent	50 percent	70 percent	90 percent	100 percent	110 percent	130 percent	150 percent
Montana:																												
Eastern	2.04	2.86	3.67	4.08	4.49	5.30	6.12	2.70	3.79	4.87	5.41	5.95	7.03	8.12	1.30	1.83	2.35	2.61	2.87	3.39	3.92	4.74	6.64	8.53	9.48	10.43	12.32	14.22
Central	2.15	3.01	3.87	4.30	4.73	5.59	6.45	2.67	3.74	4.81	5.34	5.87	6.94	8.01	1.56	2.18	2.80	3.11	3.42	4.04	4.66	4.82	6.74	8.67	9.63	10.59	12.52	14.44
Western	2.07	2.90	3.73	4.14	4.55	5.38	6.21	2.07	2.90	3.73	4.14	4.55	5.38	6.21	2.14	3.00	3.85	4.28	4.71	5.56	6.42	4.14	5.80	7.45	8.28	9.11	10.76	12.42
Wyoming	2.40	3.35	4.31	4.79	5.27	6.23	7.18	2.00	2.80	3.60	4.00	4.40	5.20	6.00	1.40	1.97	2.53	2.81	3.09	3.65	4.22	4.40	6.15	7.91	8.79	9.67	11.43	13.18
Colorado	2.47	3.46	4.45	4.94	5.43	6.42	7.41	2.81	3.93	5.06	5.62	6.18	7.31	8.43	1.63	2.28	2.93	3.26	3.59	4.24	4.89	5.28	7.38	9.50	10.55	11.60	13.72	15.82
New Mexico	1.38	1.92	2.48	2.75	3.02	3.58	4.12	3.08	4.31	5.54	6.16	6.78	8.01	9.24	1.72	2.41	3.10	3.44	3.78	4.47	5.16	4.45	6.23	8.01	8.90	9.79	11.57	13.35
North Dakota:																												
Eastern	2.45	3.43	4.41	4.90	5.39	6.37	7.35	4.39	6.15	7.90	8.78	9.66	11.41	13.17	1.93	2.70	3.47	3.86	4.25	5.02	5.79	6.84	9.58	12.31	13.68	15.05	17.78	20.52
Central	2.12	2.96	3.81	4.23	4.65	5.50	6.34	3.92	5.49	7.06	7.84	8.62	10.19	11.76	1.45	2.03	2.61	2.90	3.19	3.77	4.35	6.04	8.45	10.86	12.07	13.28	15.69	18.10
Western	2.05	2.87	3.69	4.10	4.51	5.33	6.15	3.54	4.96	6.38	7.09	7.80	9.22	10.64	1.29	1.81	2.32	2.58	2.84	3.35	3.87	5.60	7.84	10.08	11.20	12.32	14.56	16.80
South Dakota:																												
Eastern	3.24	4.54	5.83	6.48	7.13	8.42	9.72	4.66	6.52	8.39	9.32	10.25	12.12	13.98	2.09	2.93	3.76	4.18	4.60	5.43	6.27	7.90	11.06	14.22	15.80	17.38	20.54	23.70
Central	2.70	3.77	4.85	5.39	5.93	7.01	8.08	3.74	5.23	6.72	7.47	8.22	9.71	11.20	1.38	1.93	2.48	2.76	3.04	3.59	4.14	6.44	9.01	11.58	12.87	14.16	16.73	19.30
Western	3.04	4.26	5.48	6.09	6.70	7.92	9.14	3.66	5.12	6.58	7.31	8.04	9.50	10.96	1.43	2.00	2.57	2.86	3.15	3.72	4.29	6.70	9.38	12.06	13.40	14.74	17.42	20.10
Nebraska:																												
Eastern	3.86	5.40	6.94	7.71	8.48	10.02	11.56	5.62	7.86	10.11	11.23	12.35	14.60	16.84	3.00	4.19	5.39	5.99	6.59	7.79	8.98	9.47	13.26	17.05	18.94	20.83	24.62	28.41
Central	3.42	4.80	6.16	6.85	7.54	8.90	10.28	4.74	6.64	8.54	9.49	10.44	12.34	14.24	1.99	2.79	3.58	3.98	4.38	5.17	5.97	8.17	11.44	14.71	16.34	17.97	21.24	24.51
Western	2.98	4.16	5.36	5.95	6.54	7.74	8.92	3.74	5.23	6.72	7.47	8.22	9.71	11.20	1.44	2.02	2.59	2.88	3.17	3.74	4.32	6.71	9.39	12.08	13.42	14.76	17.45	20.13
Kansas:																												
Eastern	5.12	7.17	9.22	10.24	11.26	13.31	15.36	6.16	8.62	11.08	12.31	13.54	16.00	18.46	4.32	6.05	7.78	8.64	9.50	11.23	12.96	11.27	15.78	20.29	22.54	24.79	29.30	33.81
Central	3.78	5.28	6.80	7.55	8.30	9.82	11.32	5.15	7.21	9.27	10.30	11.33	13.39	15.45	2.97	4.16	5.35	5.94	6.53	7.72	8.91	8.92	12.50	16.06	17.85	19.64	23.20	26.78
Western	2.77	3.88	4.99	5.54	6.09	7.20	8.31	4.10	5.74	7.38	8.20	9.02	10.66	12.30	1.85	2.59	3.33	3.70	4.07	4.81	5.55	6.86	9.61	12.36	13.73	15.10	17.85	20.60
Oklahoma:																												
Eastern	6.25	8.75	11.25	12.50	13.75	16.25	18.75	5.52	7.74	9.94	11.05	12.16	14.36	16.58	4.80	6.71	8.63	9.59	10.55	12.47	14.38	11.78	16.48	21.20	23.55	25.90	30.62	35.32
Central	5.18	7.26	9.33	10.37	11.41	13.48	15.56	4.94	6.92	8.90	9.89	10.88	12.86	14.84	4.16	5.83	7.50	8.33	9.16	10.83	12.50	10.09	14.13	18.16	20.18	22.20	26.23	30.27
Western	3.96	5.55	7.14	7.93	8.72	10.31	11.90	4.30	6.01	7.73	8.59	9.45	11.17	12.88	3.29	4.61	5.92	6.58	7.24	8.55	9.87	8.26	11.56	14.87	16.52	18.17	21.48	24.78
Texas:																												
Eastern	5.84	8.18	10.51	11.68	12.85	15.18	17.52	5.05	7.07	9.09	10.10	11.11	13.13	15.15	4.88	6.82	8.78	9.75	10.72	12.68	14.62	10.89	15.25	19.60	21.78	23.96	28.31	32.67
Central	4.06	5.68	7.30	8.11	8.92	10.54	12.16	3.60	5.05	6.49	7.21	7.93	9.37	10.82	3.72	5.21	6.70	7.44	8.18	9.67	11.16	7.66	10.72	13.79	15.32	16.85	19.92	22.93
Western	1.90	2.65	3.41	3.79	4.17	4.93	5.68	3.23	4.52	5.81	6.46	7.11	8.40	9.69	2.32	3.25	4.18	4.64	5.10	6.03	6.96	5.13	7.18	9.23	10.26	11.29	13.34	15.30
Minnesota	3.18	4.44	5.72	6.35	6.98	8.26	9.52	5.23	7.32	9.41	10.46	11.51	13.60	15.69	2.91	4.07	5.24	5.82	6.40	7.57	8.73	8.40	11.76	15.12	16.80	18.48	21.84	25.20
Iowa	4.26	5.97	7.68	8.53	9.38	11.09	12.80	5.74	8.03	10.32	11.47	12.62	14.91	17.20	3.86	5.40	6.94	7.71	8.48	10.02	11.56	10.00	14.00	18.00	20.00	22.00	26.00	30.00
Missouri	5.94	8.32	10.69	11.88	13.07	15.44	17.82	6.04	8.46	10.88	12.09	13.30	15.72	18.14	4.86	6.80	8.75	9.72	10.69	12.64	14.58	11.98	16.78	21.57	23.97	26.37	31.16	35.96
Arkansas	7.26	10.17	13.08	14.53	15.98	18.89	21.80	5.67	7.94	10.21	11.34	12.47	14.74	17.01	5.16	7.22	9.29	10.32	11.35	13.42	15.48	12.94	18.11	23.28	25.87	28.46	33.63	38.80
Louisiana	6.96	9.74	12.53	13.92	15.31	18.10	20.88	7.94	11.11	14.28	15.87	17.46	20.63	23.80	5.44	7.61	9.78	10.87	11.96	14.13	16.30	14.90	20.85	26.81	29.79	32.77	38.73	44.68

The autumn precipitation histograms have some peculiar aspects. Those for the western and the eastern groups represent almost normal distributions with the same approximate mode in each case, 96 percent. However, wide variations between them are indicated, the eastern showing a larger number at the central group. For the central Plains there is shown an interesting bimodal distribution. It is far from normal, but the reason is obscure.

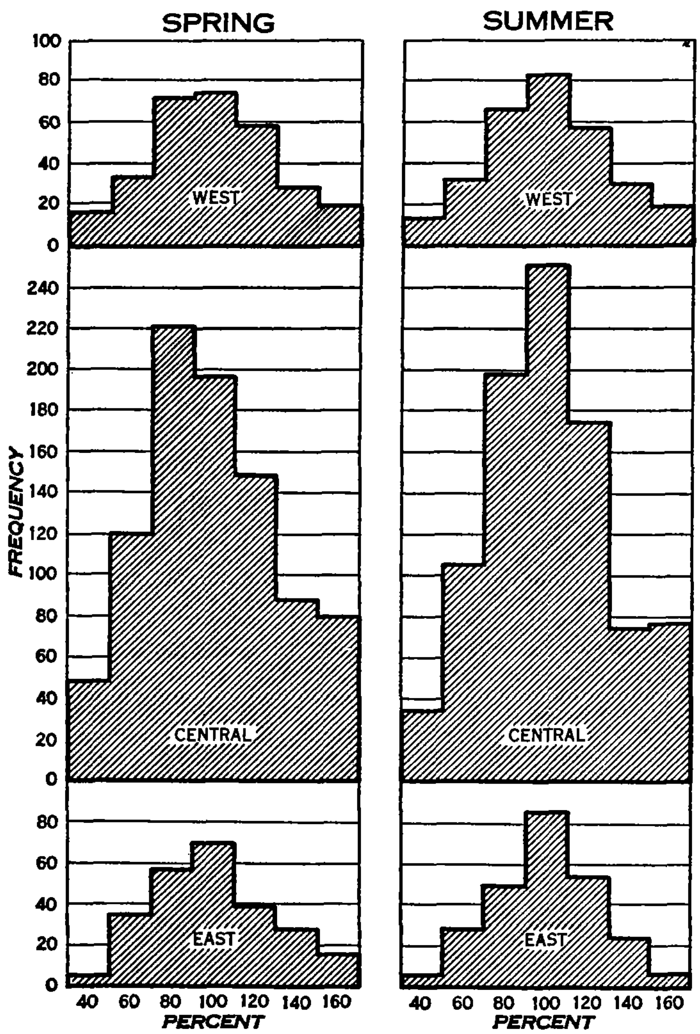

FIGURE 5.—Histograms of precipitation. Upper figure for Western Great Plains: Montana, Wyoming, Colorado, and New Mexico. Central figure for Central Great Plains: North and South Dakota, Nebraska, Kansas, Oklahoma, and Texas. Lower figure for Eastern Great Plains: Minnesota, Iowa, Missouri, Arkansas, and Louisiana.

The histograms for the March-August precipitation represent a closer approach to a normal distribution than is shown for the shorter period. In all cases the mode is only 1 or 2 percent removed from the mean, indicating a distribution very near normal. While the western and central Plains again show a tendency to skewness, the frequencies in the eastern portion are so nearly normal that no unusual features are apparent.

The average annual precipitation in the Great Plains decreases irregularly from east to west and any study of this area should take this feature into account. Therefore, as the Central States were divided into three sections corresponding to eastern, central, and western subdivisions, these were combined into definite areas as the east-central, central, and west-central Great Plains.

The histogram for the precipitation in these areas is given in figure 7. The east-central diagram is quite markedly skewed with the mode 92 percent, or definitely

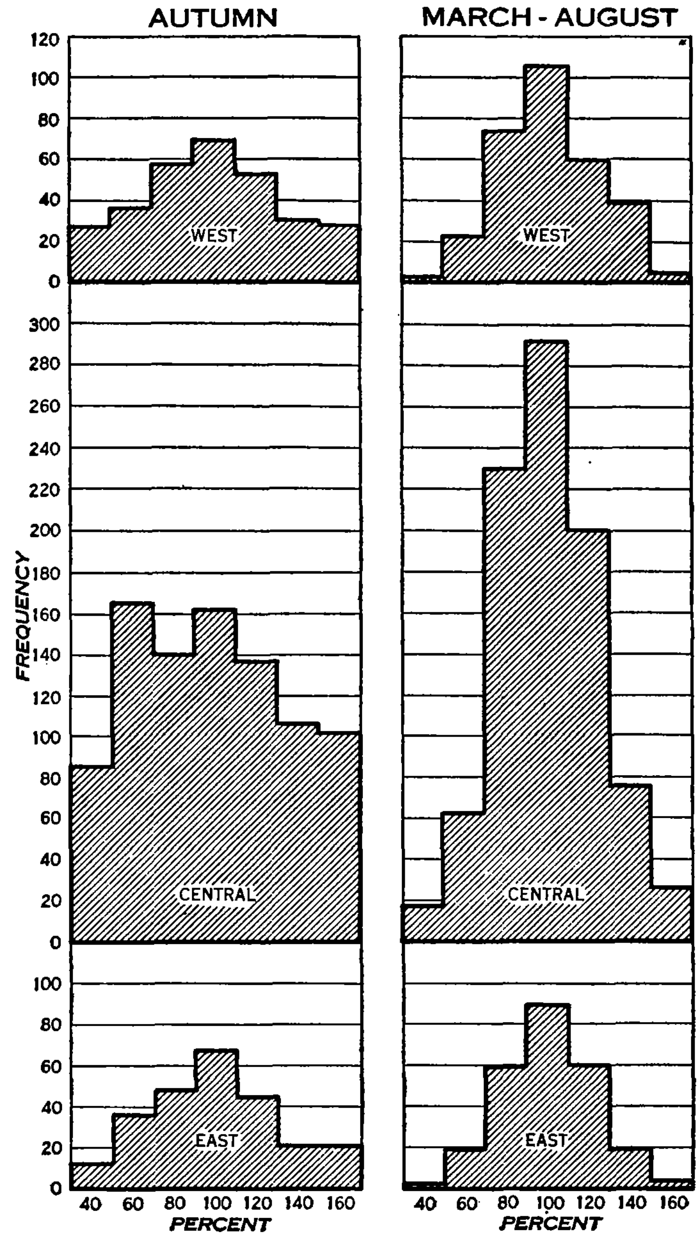

FIGURE 6.—Histograms of precipitation. Upper figure for Western Great Plains: Montana, Wyoming, Colorado, and New Mexico. Central figure for Central Great Plains: North and South Dakota, Nebraska, Kansas, Oklahoma, and Texas. Lower figure for Eastern Great Plains: Minnesota, Iowa, Missouri, Arkansas, and Louisiana.

toward the lesser amounts. A great preponderance of subnormal precipitation frequency is shown in the central diagram, where the approximate mode is 90 percent, while a still greater skew tendency becomes apparent in the west-central area where the most frequent group is dominately 70–89 percent, with the mode 85 percent or slightly above the median of this group.

Summer precipitation, on the other hand, as shown both in figure 7 and in the general histograms, reverts closely to the so-called "normal" distribution. The preponderance is clearly on the mean groups, with the eastern diagram almost normally distributed. However, the frequencies in the central and western group again tend toward the lesser amounts, with the modes 95 and 96 percent, respectively. The central diagrams show a tendency toward increased frequencies in the 150+ percent group, probably due to a number of heavy rains.

Autumn precipitation, as before, represents an abnormal condition. Undoubtedly there are some phenomena

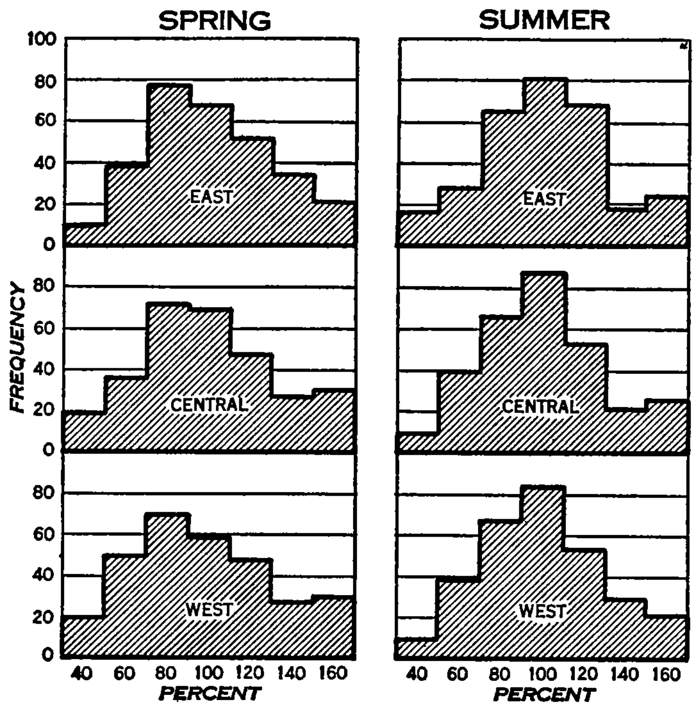

FIGURE 7.—Histograms for Sectional Precipitation. Upper figure for East-Central Great Plains: Eastern divisions of North and South Dakota, Nebraska, Kansas, Oklahoma, and Texas. Central figure for Central Great Plains: Central divisions of North and South Dakota, Nebraska, Kansas, Oklahoma, and Texas.

connected with autumn rains that definitely cause these abnormal distributions. The east-central diagram is probably the nearest approach to a "normal," but even this shows a rapid increase in the lower frequencies that effectively counteracts any weight the higher ones might give. The absence of a pronounced central tendency, such as a normal distribution would require, is also striking. In this distribution the approximate mode is 90.

The diagram for the central Great Plains, just as abnormal as the general one, again is characterized by light precipitation, shown by the dominant frequency of 50–69 percent. The mode in a distribution of this type is almost impossible to determine with any great degree of accuracy, hence it was not computed. The western Great Plains, however, represent the most abnormal distribution yet encountered. The mode approximately falls both in the 50–69 percent and 90–109 percent frequencies.

The March-August precipitation, as before, shows a general tendency to an ideal normal distribution. The mode for the east-central diagram is practically the same as the mean, while that for the central diagram is only 1 percent below the mean. The west-central group is again markedly abnormal, with the frequencies grouped heavily around the midpoint, the three central groups being within 17 of each other. The mode in the latter diagram is only 98, indicating the great preponderance of the central groups.

The general trend of precipitation is an important matter in these areas, and it is of considerable interest that figure 9 shows quite similar trend tendencies in many sections. In a study of figure 9, it should be borne in mind that each entry represents a 5-year average up to and including the date of entry.

In the trend study no effort was made to group the States into major sections of the Plains as was done for the histograms. The general tendencies are not uniform throughout the area and the individual State trends were believed to be of more dominant importance. The erratic tendencies of autumn precipitation were not believed of sufficient value to include and, consequently, figure 9 contains only the March–August data.

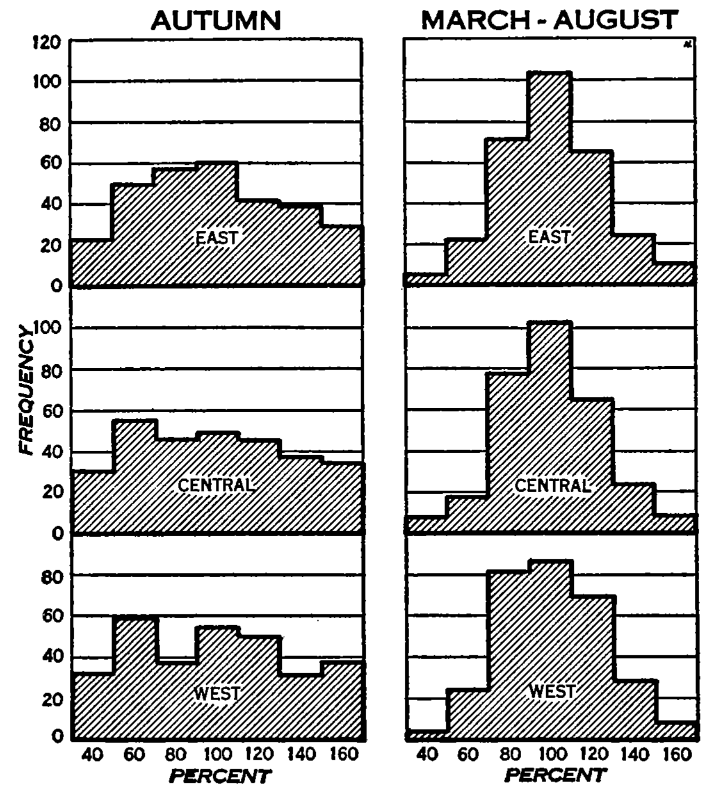

FIGURE 8.—Histograms for Sectional Precipitation. Upper figure for East-Central Great Plains: Eastern divisions of North and South Dakota, Nebraska, Kansas, Oklahoma, and Texas. Central figure for Central Great Plains: Central divisions of North and South Dakota, Nebraska, Kansas, Oklahoma, and Texas.

A 5-year moving average of percent of normal precipitation for North Dakota for the period March-August, inclusive, is shown in the figure. It shows for the different sections of the State quite similar trends. The period 1894–1909 was one of generally adequate precipitation in all parts of the State, although the excesses were not so marked in the central and western areas and declined to subnormal in the western section by 1901. The general decline in western North Dakota may be said to have begun in 1905 as none of the subsequent years approaches the peak of that year. There was some recovery from 1910 to 1916 and again from 1921 to 1928, but from the latter year through 1936 the period was one of generally deficient precipitation. Similar conditions prevail in the central and western sections and, although there was a brief tendency toward recovery in 1936, the general trend is still to below normal.

In South Dakota marked variations are indicated between the east, central, and western sections. The first two show quite similar tendencies, with increasing precipitation from 1891 to 1909, a marked decline through 1913, rapid recovery to 1917 or 1918, and a gradual and persistent decline from then through 1936. In the east a

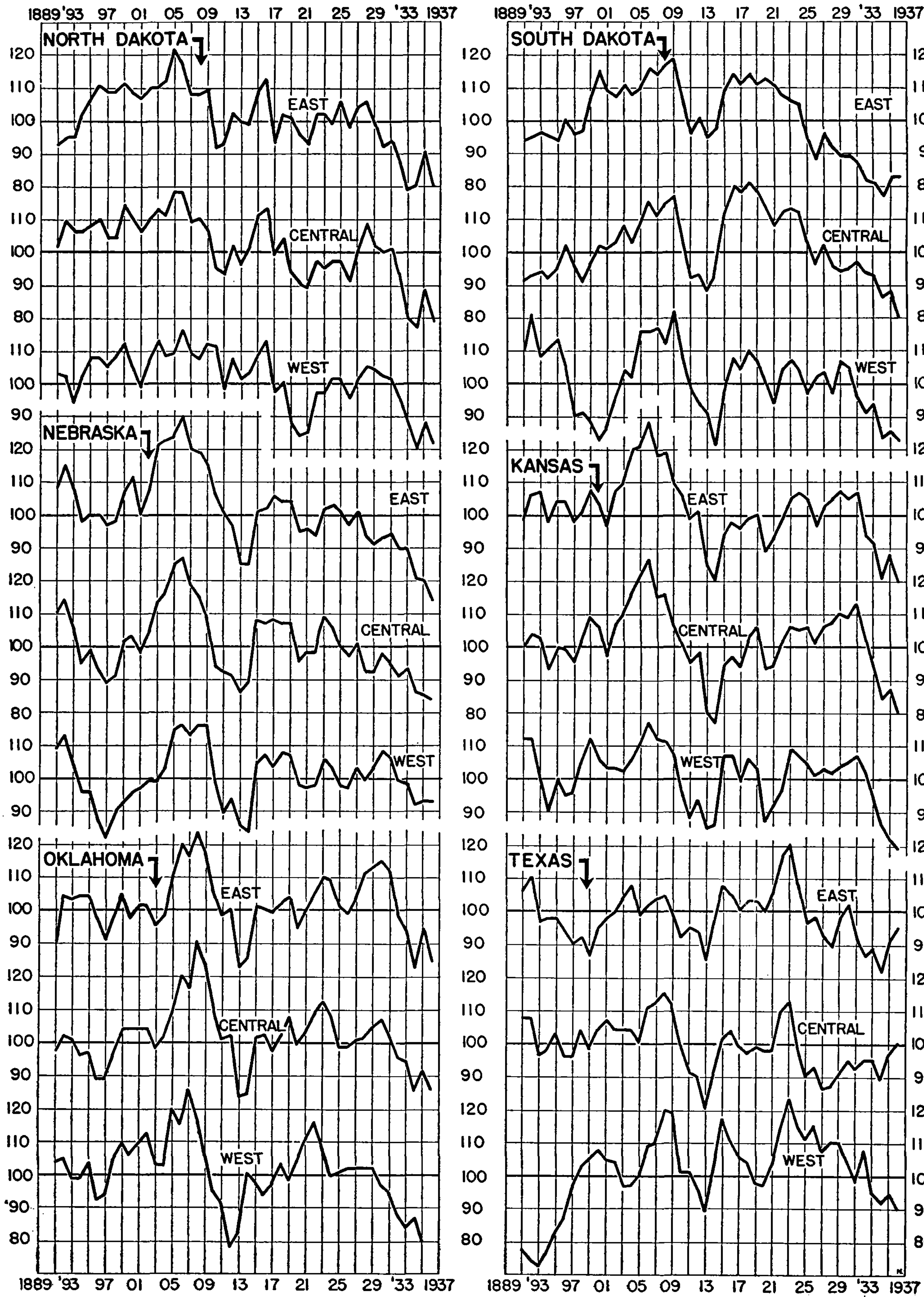

FIGURE 9.—Five-year moving averages of percent of normal precipitation for March-August.

break in the downward trend appears in 1935 and 1936, but is too indefinite for significant appraisal. The west shows a decline from a 5-year average of 120 percent in 1892 to 83 percent in 1900, a sharp recovery to the maximum of 122 in 1909, another decline to the minimum of 81 in 1914, partial recovery to 110 in 1918, and a general decline thereafter.

In Nebraska the east and central portions again agree fairly closely, while the western deviates somewhat from these. In the first two areas there are general peaks of 130 and 127 percent, respectively, in 1906, followed by a decline to 1913–14, then a recovery to 1917 in the east and 1923 in the central; thereafter both curves decline steadily to 1936. The west shows a rapid rise from the minimum in 1897 to a general high level from 1905 to 1909, the depression following agrees with the central and eastern curves, but the last decline does not begin until 1930 and is neither as abrupt nor as deep as in the central and east, averaging only 93 percent for the 5 years ending in 1936.

In Kansas wide fluctuations in the curves are shown, particularly in the eastern part where the maximum of 128 percent in 1906 is followed in 1914 by a minimum of 80 percent. The other minimum of the period occurs in 1936, with the same percentage. The central section shows the same tendencies, but the minimum in 1914 of 77 percent is the lowest of record to 1936. The actual recession is less in the west. In the west the fluctuations are more frequent than in other areas, but are of smaller amplitude. The maximum of 1906 is not as high as in the other cases and, while the minimum of 1936 is the lowest of record for this division, it is not as deep as that of 1914 in the central area. Generally, Kansas rainfall for this March-August period shows no long-time stabilization.

In Oklahoma the depression in 1934–36 has been equaled or exceeded in 1913 in all divisions. The maximum in 1907–08 is somewhat later than in the other States. The secondary maximum of 1930 in the eastern district is not as pronounced in the central and is lacking in the west. The precipitation in the west declined steadily from 1922 to 1936, although there was a period from 1925 to 1929 with slightly above normal precipitation.

In Texas there is a marked variance between the sections for the period 1891–1900. In the east the curve begins substantially above normal and declines to 1899, while in the central it fluctuates above and below normal for this period. In the west, however, the period begins much below normal, declines slightly to 1893, then recovers with a continuous advance to 1900. Throughout the remainder of the curve there is agreement rather closely with other areas until 1923, with maxima in all divisions. The central and eastern curves then decline to 1927 and 1934, respectively. Thereafter, the central section continues somewhat below normal for a number of years, but reaches normal again in 1936. The eastern graph makes a brief recurve above normal in 1936. In the west, however, there is a progressive decline in precipitation from 1925 to 1936, broken by occasional recoveries, but maintaining a continuous downward trend, ending 10 percent below normal in 1936.

It is interesting to observe in this series of curves that the eastern, or subhumid section of the Plains shows as wide variations as the western. For example, in North Dakota the range is from 121 percent to 79 percent in the east, an amplitude of 42 percent; in the central 118 to 78 percent, or of 40 percent; and in the west 116 to 80, or only 36 percent.

In the other States the maxima and minima percentages and ranges are as follows:

	Maximum	Minimum	Range
South Dakota:	*Percent*	*Percent*	*Percent*
East	119	77	42
Central	121	80	41
West	122	81	41
Nebraska:			
East	130	74	56
Central	127	84	43
West	116	82	34
Kansas:			
East	128	80	48
Central	126	77	49
West	117	79	38
Oklahoma:			
East	124	82	42
Central	130	83	47
West	126	78	48
Texas:			
East	121	81	40
Central	115	80	35
West	124	73	51

A significant trend is the wide fluctuations in western Oklahoma and western Texas. The latter shows the greatest range of any of the States, and it is particularly interesting that portions of these districts are included in the so-called "dust-bowl." Such wide fluctuations as are shown in these areas where the average effective rainfall is precariously near the minimum must be detrimental to a settled agriculture. This is pointed out very strikingly by Kincer (**9**) in the following quotation:

> There is a well-recognized tendency for precipitation in the Plains Region to show several successive years of comparatively generous rainfall, followed in turn by several years with deficient moisture, and this renders farming by ordinary methods precarious in many of the drier western portions of the section. Abundant crops in years of ample moisture encourage the western extension of the cultivated area, but the records show that these are only temporary conditions, and are likely to be followed by years of drought when the rainfall is entirely insufficient to mature crops. Disaster is sure to follow unwise agricultural adventures of this kind.

It was previously mentioned that an attempt would be made to examine the data for the various sections to determine, if possible, whether the divisions as herein used represent distinct climatic provinces. The evidence thus far submitted indicates to some extent that the sections are generally in fair agreement, at least as regards frequencies of different amounts of precipitation.

However, a striking phase is the variation in the 5-year moving average curves between States. For example, those for eastern North and South Dakota show marked divergencies between 1893 and 1899, and again between 1916 and 1928. The central portions of these States also show similar disagreements, especially between 1916 and 1925. In the west the curves are out of phase until 1905, but agree roughly from then to 1936, except for the years 1912–14. There seems to be a slight tendency toward agreement between central North Dakota data and western South Dakota data. The eastern and central sections of the respective States also seem to be in slight agreement.

The several sections of South Dakota and Nebraska are in quite close agreement, except for a deflection of the minima in western Nebraska to the left of that for South Dakota, or approximately 3 years earlier.

The comparison between Nebraska and Kansas shows a very close agreement generally. In the eastern portions there is a tendency for Kansas to have higher values from 1927–31, as well as from 1926–1932 in central districts. The western sections show quite close agreement, the only marked discrepancy being in the years 1898–1901 when Kansas recorded somewhat higher values.

Kansas and Oklahoma data also agree very well, except in the deflection of the Oklahoma maxima to the right, or two years later than Kansas, in all sections. The western portions of these States show more deviations between the curves than the central and eastern districts. Reversals of trend for these curves are indicated in 1902, 1907, 1912, 1915, 1916, 1920, and 1930–31.

Oklahoma and Texas, however, again indicate a tendency similar to those for the Dakotas. Eastern Oklahoma agrees fairly well with central Texas especially during early years. A reversal of trend occurs during the years 1927–31, when eastern Oklahoma data show a tendency to above normal values and Texas the reverse. Agreement is quite close between central Oklahoma and western Texas, the only serious difference occurring in early years, between 1891–1896, which probably may be due to nonhomogenous data. The western portions of these States, however, are in fair agreement, also indicating that the central and western Oklahoma data are more nearly comparable with western Texas.

As general conclusions on the matter of section similarity, the divisions in the central portion of the Plains seem to be well chosen, but adjustments are indicated in both the northern and southern extremes. As considerable labor would be involved in these redistributions, and the adjustments of only minor climatic importance, it scarcely seems advisable under present circumstances.

Considering the Great Plains, as a whole, there is remarkable uniformity in its precipitation distribution. The general tendency to a moderately skewed distribution is of course, to be expected, but the marked bimodal distribution of autumn precipitation awaits some logical explanation. Indications point toward a great frequency of very light precipitation as the cause. This frequency of precipitation in the 50–69 percent groups indicates an average daily rainfall of only 0.13 inch, based on an average precipitation for the area of 1.94 inches and 5 days of rain per month.

Several clues as to the lack of substantial precipitation are offered by Holzman (**10**). The theory that air masses may remove moisture from the land and only reprecipitate it under favorable conditions, and then only in insignificant amounts, may contribute largely to the lack of appreciable precipitation in the Great Plains in autumn. At this season the general movement of air masses ordinarily becomes somewhat accelerated and the Great Plains becomes invaded more frequently by the large Pc masses and thus conditions become more unfavorable for appreciable precipitation. Also, the more definite movement of the PM and PP air contribute more toward the "Chinook" effect, thus again reducing the chances for significant precipitation. It also appears that definite invasion of the region by an active air mass, probably from the Southwest or Northwest is necessary to substantial rainfall, and only in this event would the daily amounts be of sufficient magnitude to increase the seasonal totals to an entirely different class frequency.

LITERATURE CITED

(1) Atlas of American Agriculture.
(2) Thornthwaite, C. Warren. The Great Plains. In *Migration and Economic Opportunity,* chapter V: 202–250.
(3) Great Plains Committee. The Future of the Great Plains (1934). Report of the Great Plains Committee, December 1936.
(4) Kincer, J. B. Daytime and Nighttime Precipitation and Their Economic Significance. MONTHLY WEATHER REVIEW, 44: 628–633, 1916.
(5) Kincer, J. B. Seasonal Distribution of Precipitation and its Frequency and Intensity in the United States. MONTHLY WEATHER REVIEW, 47: 624–631, 1919.
(6) Jefferson, Mark. Aridity and Humidity Maps of the United States. *Geographical Review* 1: 203–208, 1916.
(7) Ward, Robert DeC. Climatic Subdivisions of the United States. *Bulletin American Geographical Society XLVII:* 672–680, 1915.
(8) Thornthwaite, C. Warren. The Life History of Rainstorms. *Geographical Review* 27: 92–111, 1937.
(9) Kincer, J. B. The Climate of the Great Plains as a Factor in their Utilization. *Annals Association American Geographers* XIII: 67–80.
(10) Holzman, Benjamin. Sources of Moisture for Precipitation in the United States. U. S. Department of Agriculture Technical Bulletin 589, 1937.
(11) Mills, Frederick C. Statistical Methods, New York, 1924.

A STUDY OF THE HOURLY PRECIPITATION AT OKLAHOMA CITY, OKLA.

By H. F. ALEXANDER

[Weather Bureau Airport Station, Waynoka, Okla., October 1937]

Numerous studies of the hourly distribution of precipitation have been made during the past quarter of a century, but since all such studies are more or less local in character, it has been deemed worth while to make a similar investigation of the Oklahoma City data. Material of this kind is of value in determining rainfall insurance rates, in making local weather forecasts, in planning outdoor activities, and as a contribution to climatology.

The records for the years 1911 to 1935, inclusive, embracing a period of 25 years, were used. The data for each month, consisting of the hourly amounts and the beginning and ending of each period of precipitation, were entered on a suitable form, after which the totals and averages were obtained. All averages used in this study are for the entire 25-year periods; in cases where there was a break in the record of hourly precipitation, as often occurred during the winter months when there was no automatic record, it was deemed permissible to interpolate the hourly amounts.

A bibliography of easily accessible papers on similar investigations is appended.

AVERAGE HOURLY AMOUNTS OF PRECIPITATION

The average hourly amounts of precipitation for each of the 24 hours are given in Table 1 for the months and for the year. The average hourly amounts for the daytime (7 a. m. to 7 p. m.) and nighttime (7 p. m. to 7 a. m.) periods are given in the table also.

The data reveal the existence of a distinct diurnal period in the average hourly amounts of precipitation occurring at Oklahoma City, especially during the spring, summer, and autumn months. This characteristic begins to be apparent in March and continues throughout the summer season and into November. With the exceptions of May and July, there is a well-defined maximum period beginning just after midnight and extending until about 7 a. m.; the greatest average hourly amounts for April, June, August, and September occur between 1 a. m. and 3 a. m. There is also a well-defined secondary maximum in the late afternoon and early evening hours during the summer months.